CHAPTER 17: BOILER WATER PREPARATION Part 1

Boiler water preparation, once "clarification," "filtration," etc., has been carried out (in well water, this is generally not necessary, except for sand removal; in OSE water or purchased supply, it is also not necessary, but if the water is from the surface and is taken in natural conditions, it must be treated to make the water "clean" enough for industrial use, not necessarily potable).

However, this water, depending on its chemical values (TSD, Total Hardness, silica, etc.), and depending on the type of boiler, pressure, steam quality, etc., will require treatment to make it suitable for its intended use.

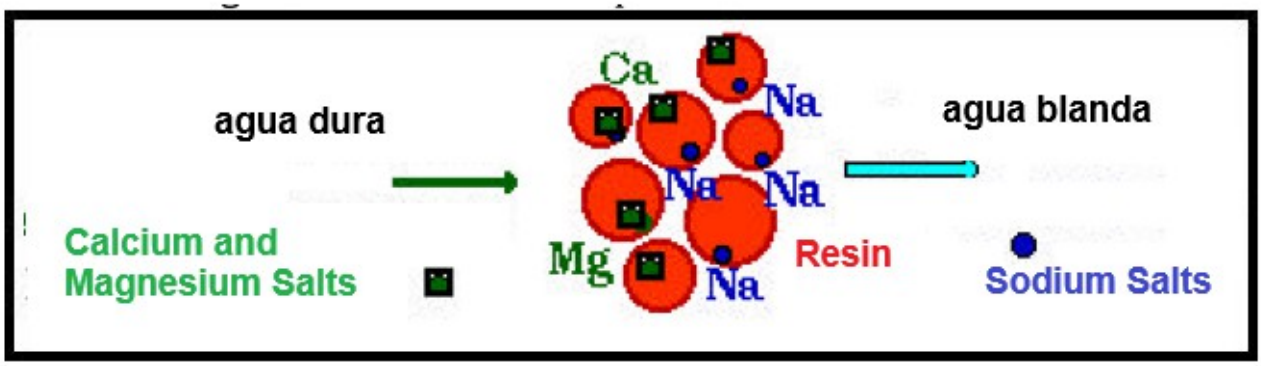
This means removing the salts that cause hardness (calcium, magnesium, iron), which can be exchanged for others that do not produce scale (such as in a water softener), or they can be completely eliminated (as in the case of distillation, precipitation, demineralization by ion exchange, reverse osmosis, etc.).

It also means removing gases (such as oxygen, CO2, etc.) using deaerators, etc.

Let's look at these topics below:

WATER SOFTENERS:

The use of ion exchangers (water softeners) in the sodium cycle is very common: it prevents sludge formation inside the boiler and reduces the amount of anti-scaling products needed (phosphates, etc.), with the drawback that it does not reduce the total dissolved salts.



The exchange material in the softener consists of small spheres (with a maximum diameter of approximately 1.2 mm) of an artificial organic material (formerly natural sands called "zeolites," which existed in some very exclusive locations), which have the property of exchanging sodium ions for calcium and magnesium ions, softening the water (other ions, such as iron, can also be exchanged).

CATION RESIN and ANION RESIN (SOURCE: indiamart.com)

The height of the resin bed must be a minimum of 600 mm (23") to prevent the formation of pathways through which hard water passes and allows the softener to "lose" hardness.

Its exchange capacity has a limit, estimated at approximately 55 grams of calcium carbonate ($CaCO_3$) per liter of resin. This means that for water with a total hardness of 100 ppm $CaCO_3$, 1 cubic meter will consume 100/55 = 1.8 liters of resin in the exchange process.

If you want to soften 10 m^3 of this water per hour, this flow rate requires a minimum of 10 x 1000/24 = 416 liters of resin in the softener bed, and will consume 1.8 x 10 = 18 liters of resin per hour.

This means that the softener will need to be regenerated every 416/18 = 23 hours. Respecting the resin volume for the maximum flow rate, regeneration times can be determined by adjusting the resin volume to suit the regeneration schedule: once a day, every two weeks, or once a week.

Once the resin is saturated with calcium and magnesium ions, it must be regenerated with sodium chloride (common salt).

The hourly capacity is very important, as a typical resin bed can handle an average of 24 liters per hour per liter of resin.

Diseño Carlos W. Thomasset

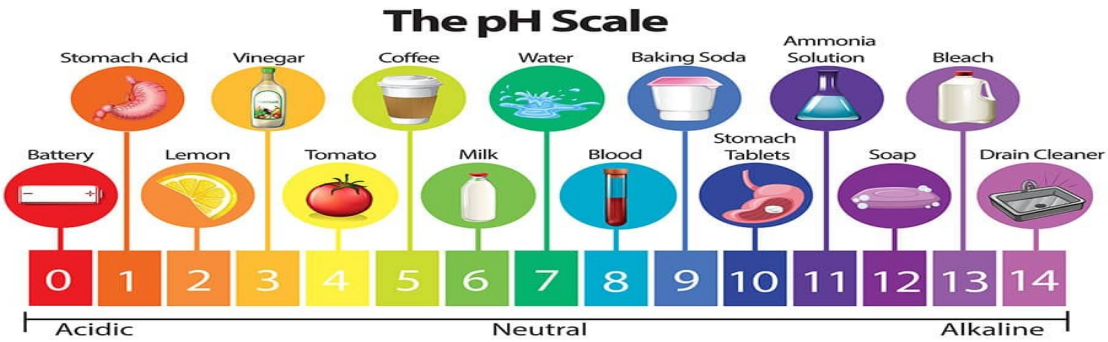
To regenerate, when brine (water with a sodium chloride or NaCl salt concentration greater than 10%) is passed through, the sodium ions displace the calcium and magnesium ions, and the sodium chloride is discharged through the drain as calcium chloride and magnesium chloride.

Therefore, when regenerating the water softener, it is important to have a specific brine concentration and to pass it through within a specific timeframe to ensure the most complete exchange possible.

Of course, this excess brine must then be removed to prevent it from flowing into the boiler (it is highly corrosive).

In other words, a water softener doesn't "remove the hardness salts," but rather exchanges the part of the salt that causes scale formation, replacing it with a non-scaling sodium ion.

However, this also has its drawbacks, as it increases the possibility of corrosion and raises the levels of "free soda," causing the pH to rise (which leads to foaming, sediment buildup, and corrosion if not limited to a maximum, generally through continuous purging and an internal chemical treatment capable of reacting with some of the sodium).



<u>Well water is generally the most problematic.</u>

One of the problems encountered when softening well water, which already contains a high level of sodium chloride (NaCl), is the self-regeneration of the water itself.

This makes complete softening difficult, and some hardness is lost due to this self-regeneration.

In these waters, it is advisable to regenerate the softener with a higher percentage of salt compared to surface water, for example, 0.200 kg of salt (NaCl) per liter of resin, instead of 0.150 kg/L.

COMMON SALT (NaCl Sodium Chloride)

Let's see how to operate a sodium cycle heat exchanger:

There are four states in which the softener can operate and three fundamental operations for its regeneration:

Normal operation

1- Backwash,

2- Brine flow (NaCl),

3- Rinse (slow flushing and fast flushing).

Normal operation:

Water normally flows from top to bottom through the softener cylinder, passing through the resin, so that calcium and magnesium ions exchange with the sodium ions present in the resin.

There is a maximum volume/flow of water that can be exchanged.

If this amount is exceeded, hardness (calcium and magnesium) will escape and will still going in the boiler feed water.

Once the system is "exhausted," meaning the water starts to become hard, it must be regenerated:

1- Backwash, 2- Brine, and 3- Rinse.

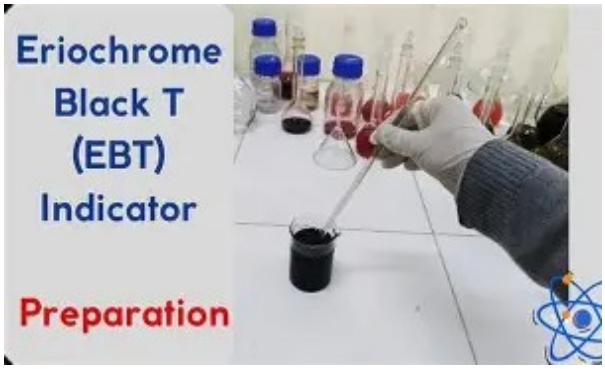
Previously, the water in the softener was tested to determine if it was soft or hard.

A special “soap” was used as a check/test; if hard water was present, it would not form soap lather (it would not saponify), while if soft water, it would immediately form lather on its surface.

If hardness had to be measured, it was proportional to the amount of soap used to form lather.

These "calibrated" soaps were specially manufactured for that purpose.

Today, more practical methods are used, such as an indicator based on Eriochrome Black T (a substance used for industrial dyeing) and a buffer (a pH regulator close to 10 for the indicator to function).



SOURCE: https://i.ytimg.com/

This indicator produces a transparent blue color in soft water and a "wine lees" color in hard water.

In this case, if hardness is to be measured, a "hardness sequestering" salt is used.

This salt is added to a sample with the indicator until the water softens. The color changes from "wine lees" to "transparent blue."

The amount of sequestering agent used (usually EDTA), depending on its concentration and the sample size, is multiplied by a factor to calculate the total hardness of the sample.

The hardness indicator for water softeners is made from Eriochrome Black T, a product widely used for dyeing, with a buffer (if used in powder form, generally ammonium chloride). A few drops of ammonia must be added to the water being analyzed to raise its pH to pH 10.

However, as a water softener indicator, it is best to use Eriochrome Black T dissolved in triethanolamine (with some buffer such as ammonium chloride).

The minimum amount of indicator should be used in each case to avoid errors in the "zero" hardness reading, since the color change of these indicators consumes some of the hardness (and they require the presence of magnesium to react; that is, in very rare waters that do not contain magnesium, a small amount of magnesium chloride must be added to the ETDA solution when preparing it to trigger the indicator reaction).

See Part 2 for the preparation of the EDTA.

1- Backwash:

The direction of water flow is reversed (from bottom to top) at a sufficient rate to remove the sludge deposited on the resin that has acted as a filter.

This water is then discharged down the drain, using a flow rate that can remove the sludge without damaging the resin.

10 to 20 minutes is sufficient (until the water is clear).

This sludge must be removed; otherwise, it allows the formation of "pathways" or "short circuits" (TRAKING) that permit the passage of hard water (loss of hardness).

It also creates a breeding ground for microorganisms that clog the resin, preventing it from functioning properly.

2- Brine or Regeneration:

Prepare the brine (10% clean, edible salt, free of iodine, fluoride, iron, etc.) in a quantity that will depend on the size of the water softener and the quality of the water being treated.

The brine is poured "slowly" (30 to 50 minutes), usually from top to bottom, discharging the effluent into the drain. Ensure that no air enters the softener; if air does, it must be removed before continuing with the brine rinse.

It is not advisable to leave the brine circulating inside the softener; this hinders resin regeneration and makes rinsing difficult.

Regeneration occurs through the displacement of the salt that was exchanged by the new salt that displaces it.

For calculating the amount of salt: 0.150 kg per liter of resin
that the softener contains, and up to 0.200 kg/L in the case of very hard water.

3-Rinse:

The rinse is to completely remove the brine remaining in the equipment.

First, perform a slow rinse (slightly stronger than the brine used for the initial rinse) for about 40 to 50 minutes.

Then, perform a quick rinse of 10 to 15 minutes with a flow rate similar to that used for backwashing (from top to bottom in both cases).

Monitor the water hardness with a hardness indicator and continue rinsing until the reading is soft.

The resins in the heat exchangers can be contaminated by various organic or inorganic elements: sludge should not be allowed to accumulate inside (it is advisable to assist the backwash with a little air when the water flow is insufficient).

Softeners exposed to these contaminants must have a pre-filter or be disinfected periodically.

The water to be softened should not contain significant amounts of sodium hypochlorite (no more than 1 ppm as total chlorine) because the resin tends to degrade.

The resins last for many years, depending on contamination and how often they are regenerated. The greatest loss occurs during backwashing, and some systems do not have a mechanism to prevent backwash loss.

During extended periods of non-use, leave the softener regenerated and flooded with water. They operate best when the water circulation is modulating, as in the case of a float valve (an on-off system is not recommended).

It is advisable to monitor the water hardness every shift (6 to 8 hours).

Today, the fastest verification method is with Eriochrome Black T-based indicators, which produce a "transparent blue" color with soft water and a "wine lees" color with hard water.

To obtain the sample, run the softener at full power for a few minutes; otherwise, there is a risk that, without water circulation, the system will produce soft water with the system "exhausted" (deceiving the operator).

Boiler softeners should be "generous" to avoid frequent regenerations (which generally result in the "loss" of hard water), and personally, I believe it is better for the operation not to be automatic.

Automatic softeners do not guarantee safe operation and can lead to errors as dangerous as introducing the "rinse" or "brine" into the boiler, incidents that have occurred causing accidents.

Automatic water softeners are generally regenerated based on a set time or the volume of water that has passed through (m^3).

Both of these can be erratic, since a boiler's energy consumption depends not only on steam production but also on condensate shortages or, in the case of m^3, variations in water hardness (such as the effect of rainfall on surface water, the mixing of water from different wells, or incomplete regeneration).

If automatic softeners are preferred, they should be monitored by a Total Hardness meter, which would trigger the regeneration cycle or bypass the hard water and sound an alarm so the boiler operator can take action.

Given all these drawbacks, manual water softeners are preferable for boilers.

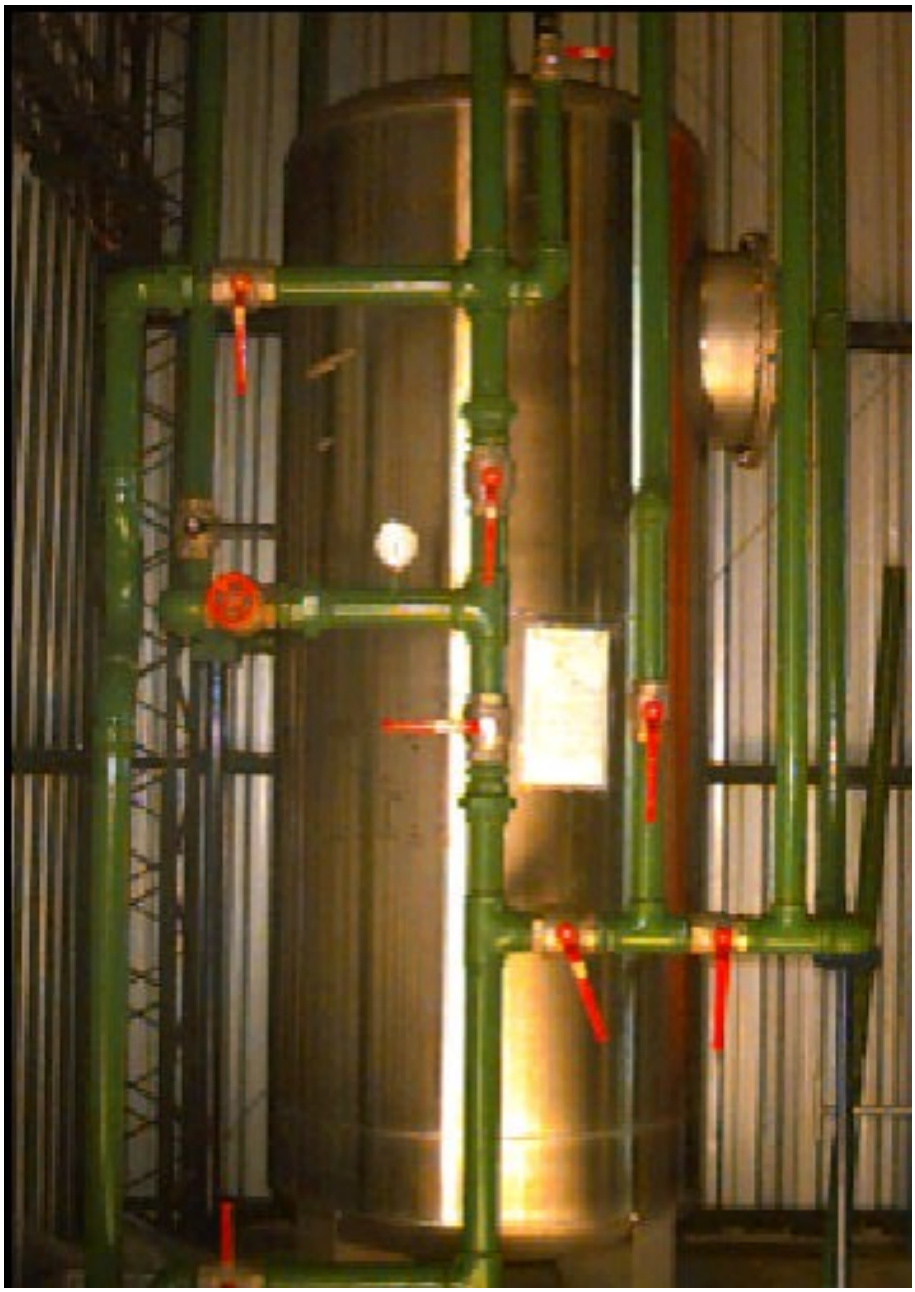
However, one problem with water softeners, whether automatic or manual, is preventing "water hammer," which occurs when they use fast-acting valves (such as solenoids or large, fast-acting pneumatic valves instead of slow-acting ones).

The rapid (almost sudden) closure of the water flow after passing through the softener causes all the dynamic energy of that water to accumulate, manifesting as a pressure increase. In some cases, this pressure can rise several times the inlet pressure, causing the resin tanks to rupture (due to the repeated pressure increases and decreases that eventually fatigue and crack the material).

These water hammer effects must be avoided; the best solution is to install float-type control valves for the water softeners in the soft water tanks (which open and close slowly following the water level), or alternatively, to install pneumatic valves with delay controls for opening and closing.

We have verified that when a water softener connected to a water pressure of 4 kg/cm² is quickly closed (as with a standard solenoid or pilot-operated valve), the pressure instantly reaches 20 kg/cm². Over time, this causes cracks in the softener's tank, which is made of thick stainless steel.

Installing a relief valve is insufficient, as there is a delay in the valve's instantaneous action. It is always advisable to use slow-acting valves in soft water tanks.



1200 Lt resin softener (C.W.T: design)

WATER DEMINERALIZATION

Water demineralization is the process of removing all dissolved salts from water that no longer contains suspended elements.

Let's look at: CHEMICAL PRECIPITATION, DISTILLATION, EXCHANGE DEMINERALIZATION, and REVERSE OSMOSIS.

To control the quality of demineralized water, the electrical conductivity of salt ions in water is used (salts or inorganic substances, and some organic substances, ionize to a greater or lesser degree.

Colloidal silica and some organic elements have practically no effect on the transfer of electrical current in water because they do not ionize easily).

The electrical conductivity allowed by salts or some organic substances in water (pure water is practically a poor conductor, meaning it is almost an insulator), when a voltage is applied between two electrodes separated by a certain distance, allows for a measurement of the amount of salts in that solution.

This measurement must be corrected for the temperature of the sample, since at higher temperatures, a greater current flows, meaning lower resistance.

This standard temperature is generally 25°C (77°F), and it can be considered that conduction increases by 2.2% for every 1°C (33.8°F) increase in temperature.

Therefore, this measurement is made either by conductivity (current flow, measured in Siemens per centimeter or micro-Siemens per cm, or µS/cm, the most commonly used unit (micro = µ = 0.000001 S, given the extremely small values, the Siemens being the unit of conduction equivalent to a circuit with a resistance of 1 Ohm when a voltage of 1 volt is applied)),

Or equivalently, by inverse resistance (resistance is measured in Ohms, the inverse in Mho, a way of expressing conductivity), which is expressed in Mho/cm or microMho/cm, or µMho/cm. (micro or µ means one millionth, or 0.000001 or 10^{-6}, given how small the conductivity can be in almost pure water between two 1 cm^2 plates at a distance of 1 cm, when the voltage is 1 volt).

But Siemens was chosen instead of Mho (both are equivalent).

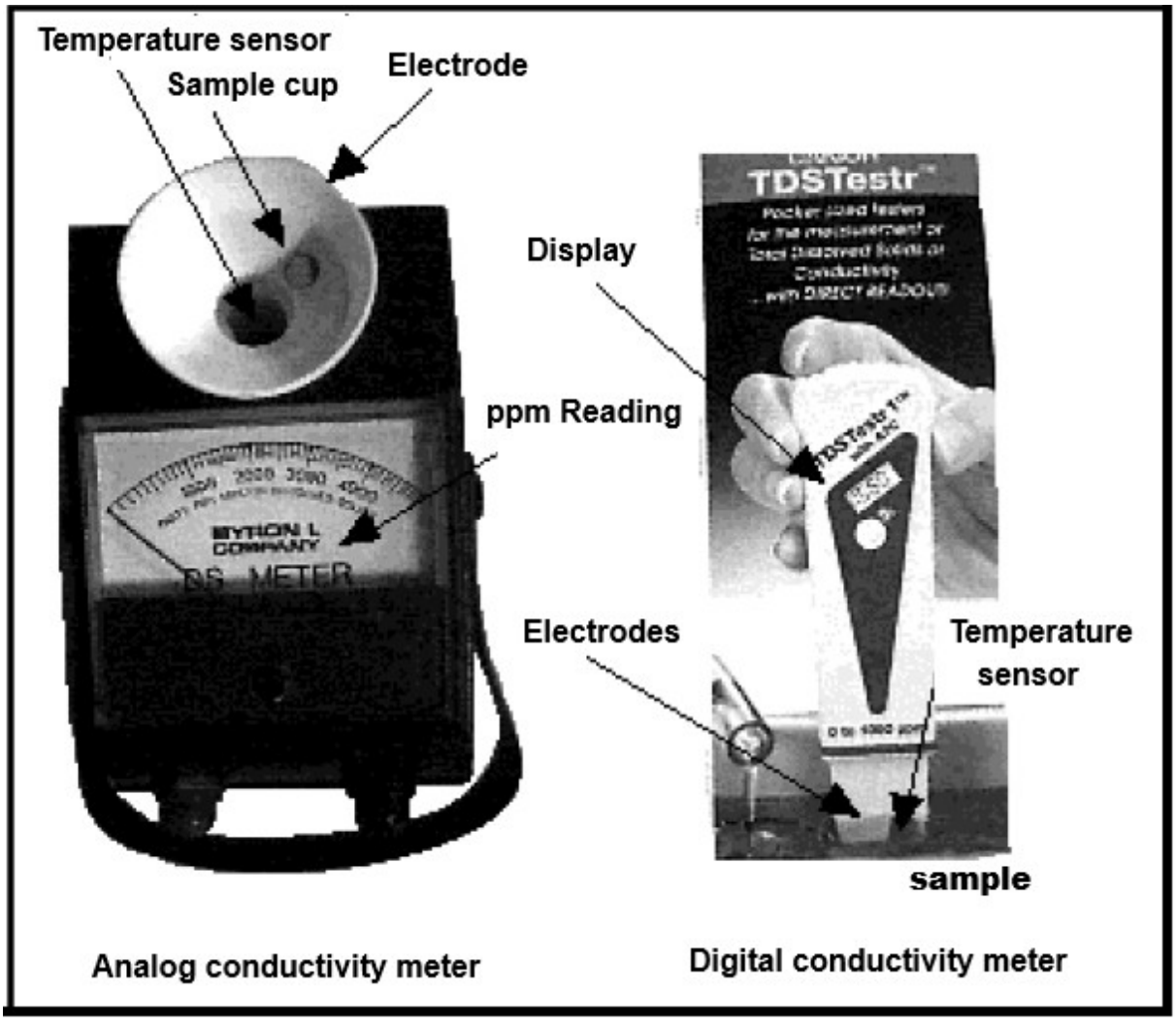
Other values related to conductivity can be expressed in millisiemens (mS, meaning one-thousandth of a Siemens, since 1 mS/cm = 1,000 µS/cm or milliMho: mMho).

Or it can be expressed as resistivity or resistance and is generally expressed as megaohm-cm (MΩ), the inverse of conductivity (mega, meaning one million times, or times 1,000,000 or 10^6), or it can be expressed in kiloohm-K - equal to 1,000 times the ohm.

The purest water achieved was established at 4.2×10^{-6} Siemens per meter at 20°C (or 0.042 µS/cm), or expressed in ohms, at 23.8 MΩ·cm.

In practice, these values are very difficult to achieve.

Parts per million (ppm), in which the salt content is expressed, refers to one unit of weight dissolved in one million (1,000,000) total units of solution, which can also be expressed in parts per thousand (ppt).



In general, we can say that the approximate values for different types of water will be (at 25°C, as is generally the case):

Super pure .....approx. 0.055 µS/cm
Distilled.....approx. 1 µS/cm
Wells.....+ 500 µS/cm
Sea water.....approx. 58 mS/cm

Surface water salinity varies in Uruguay, generally ranging from 70 µS/cm (approximately 50 ppm of salts in the Litoral region) to over 300 µS/cm (approximately 200 ppm in the Santa Lucía River during dry periods).

In wells, salinity increases, particularly in the eastern departments near the ocean, especially when the wells are deep.

The instruments used for this control generally have their readings automatically corrected for the sample temperature. They also operate with high-frequency alternating current to prevent the measuring electrodes from becoming "polarized" (i.e., covered with a gas from the decomposition caused by the current, which would alter the reading, since alternating current depolarizes in each half-cycle).

However, be careful; remember that silica and other organic elements may be present and the conductivity meter will not detect them.

Instruments can have analog readings (instruments with needles) or digital readings (instruments with screens, like calculators).

Both types of instruments must be calibrated periodically (with a sodium chloride solution specially prepared for this purpose; in boiler water, the calibration solution can be 4,500 µS/cm, equivalent to 3,000 ppm, not corresponding to 3 g/L of NaCl and water solution, but to a lower value, 2,350 mg/L of sodium chloride).

Keep their electrodes clean (using alcohol, preferably isopropyl, or sometimes a dilute acid solution—for example, 5-10% hydrochloric acid—rinsing thoroughly after a few minutes).

After cleaning the electrodes, calibrate them with the solution, allowing sufficient time to compensate for temperature variations (today, virtually all instruments have automatic temperature compensation at 25°C (77°F).

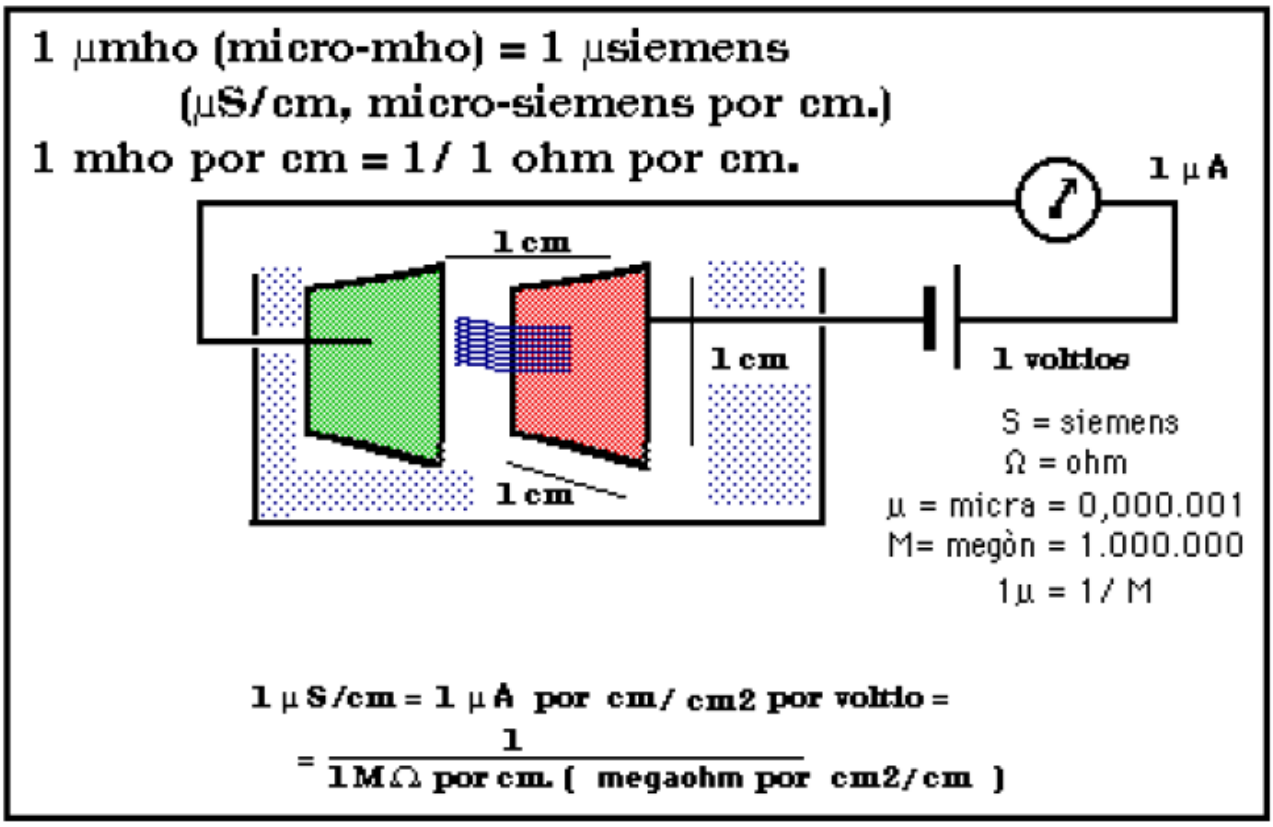
NOTE: Like pH meters, conductivity meters, if they are low-cost instruments (costing only a few dollars), will quickly lose their calibration and give false readings (inaccurate, unreal values).

Conductivity meters for monitoring demineralized water (fixed installations) generally have an automatic function that "aborts" (and triggers an alarm) if the water's conductivity exceeds the regulated level.

It's important to analyze for silica, as it can be present even with low conductivity readings.

The desired values depend on the demineralization system. Generally, we can say that 1.5 µS/cm is equivalent to 1 ppm, or 0.66 ppm per µS/cm (in boiler and natural water), and less than 0.6 ppm per µS/cm (in demineralized water or condensate).

Let's visualize the above relationships:



When measuring TDS (Total Dissolved Salts) in boiler water using a conductivity meter, if the sample isn't adjusted to a neutral pH, we're actually measuring conductivity (the higher the pH, the higher the conductivity, with the same total dissolved salts; what changes is the type of salts).

To adjust the reading to a neutral pH, non-ionizing organic acids (such as gallic acid, 3,4,5-trihydroxybenzoic acid) are used.

But in reality, what most affects boiler performance is not the quantity of dissolved salts, but the type of salts that alter the water's surface activity, thereby affecting internal circulation (potentially causing foaming, which promotes carryover, or even cutting off internal circulation, leading to insufficient local cooling that can even cause a fire-tube boiler to collapse).

In reality, when we don't adjust the pH, it's the conductivity value that we must respect, because it's the one that affects us most (and by setting a limit in ppm, corresponding to a specific maximum conductivity value, we are protecting against internal circulation problems; that is, measuring without adjusting the pH, or otherwise speaking in terms of conductivity and not ppm).

There is a tendency to be misled by this reasoning, since previously dissolved solids were measured by "evaporation" (after filtration), or by a "weighing" densimeter (with a "density" salinometer corrected for sample temperature).

Both systems do not take into account the conductivity of the water, which could be close to the desired TDS value, but in a risk zone for the internal circulation of the boiler.

Always remembering that this conductivity method does not measure the presence of silica, which generally does not affect the conductivity of the water

But can be a dangerously high threshold, especially when generating superheated steam for steam turbines, which are seriously affected by silica-laden water carryover.

CHEMICAL PRECIPITATION

Initially, in early steam boilers (along with distillation), salts were extracted by adding chemicals (lime, soda, phosphates, magnesium, etc.) to precipitate the dissolved salts, followed by filtration to remove any remaining suspended elements.

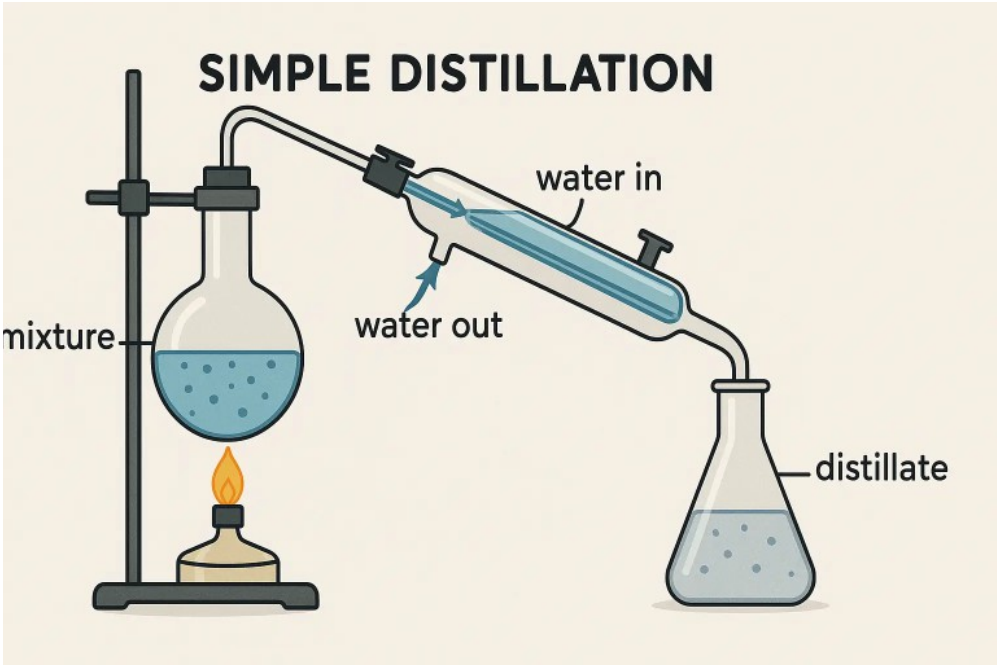
This involved veritable water treatment plants, with dosing, mixing, sometimes heating, precipitation, filtration, etc. The resulting water has a lower salt content, but not enough to be considered "pure."

It is still a valid method when used in combination with other demineralization processes to obtain "pure" water (with or almost no salts), since in water with high salt content or salts that precipitate easily, the other processes may not work correctly.

Let's look at the processes that "fine-tune" water purification (distillation, demineralization, reverse osmosis).

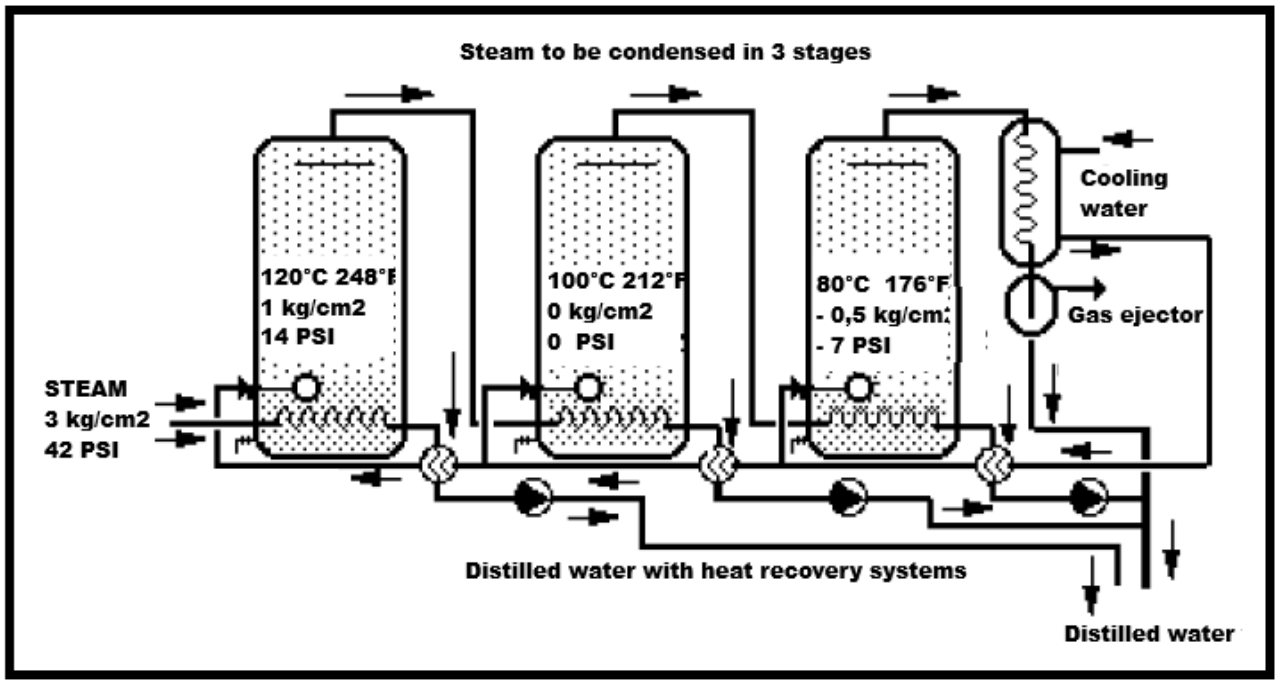
DISTILLATION

In the past, near-complete demineralization of water was achieved through evaporation and condensation (stilling distillers). By repeating the process, a fairly acceptable level of water purity was obtained.



This distillation process consumes energy (steam, direct heating, electricity, etc.). To improve efficiency, it can be carried out in several stages, taking advantage of the "latent" heat of each stage and the sensible heat of the "distilled" water. This type of still can be a multi-stage distiller (in series) or a single-stage distiller (in parallel).

Using the distillation vapors in subsequent stages reduces energy consumption, as the process is repeated at a lower pressure, with the final stages occurring below atmospheric pressure. (Alternatively, mechanical "thermo-compression" is used, compressing the distillate vapor to capture the "latent heat" of the steam, which is then reused to heat the water to be evaporated.)



Water purity is measured by its conductivity.

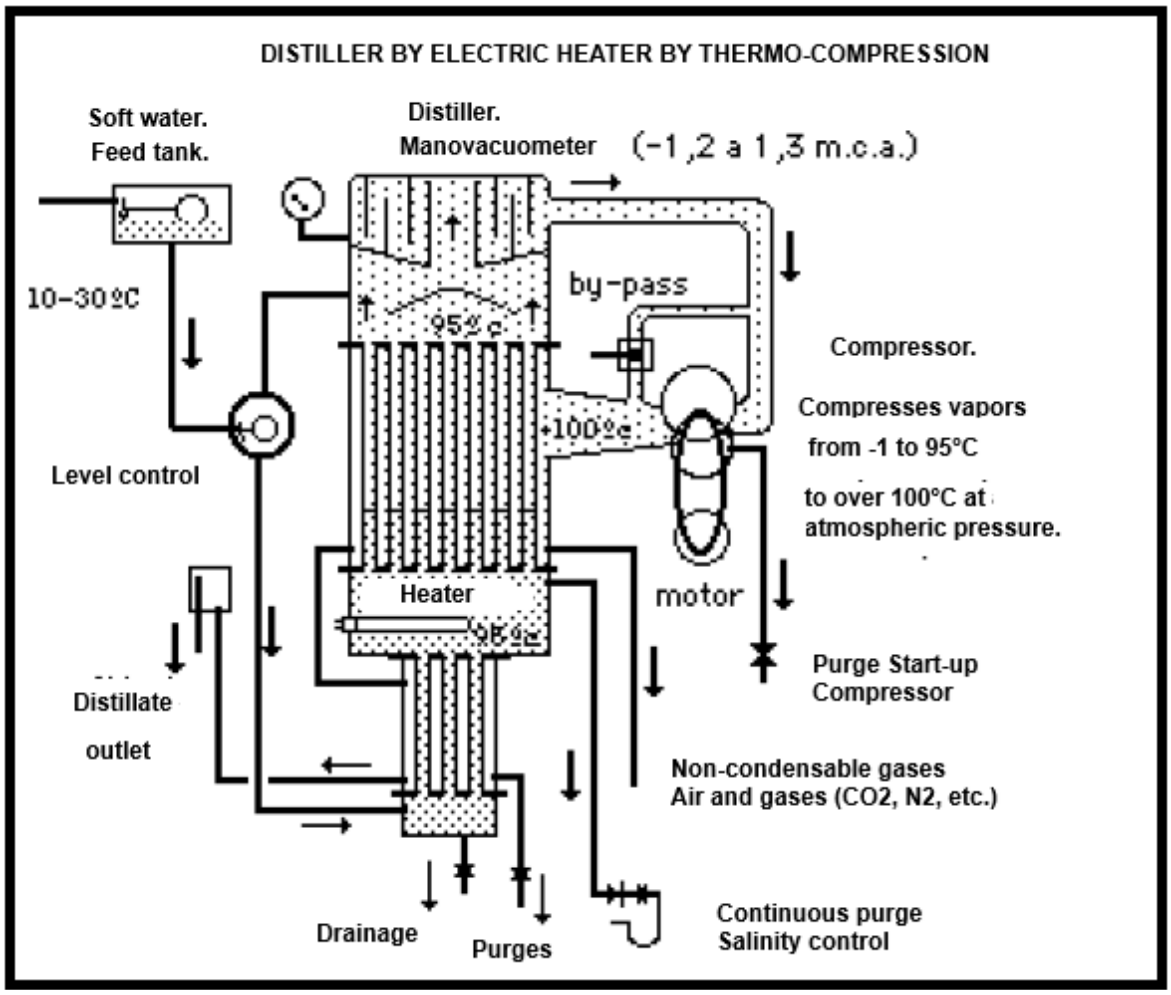
Although silica—SiO2—is not detected because it is non-ionizable, this can be a very serious problem, given that silica produces very hard, insulating scale and, in medium- and high-pressure boilers that operate with turbines, can scale the turbine blades (reducing efficiency and causing imbalances that result in vibrations that can destroy the turbine).

One of the problems with distillers is the scaling that occurs within the distiller itself; another is the management required to prevent the carryover of salts from the distilled water into the steam.

The resulting water purity is quite good; repeating the process achieves a purity almost as good as that obtained through demineralization by exchange.

One of the advantages of distillation is that, because it is carried out at a specific temperature, the distilled water is disinfected, generally resulting in water free of pyrogens (contaminating microorganisms), provided the distillation is performed at a sufficiently high temperature (this is not the case when distilling below 100°C (212°F), i.e., under vacuum—below atmospheric pressure—in an attempt to increase thermal efficiency).

One of the reasons for carryover in distillers can be: excess salts due to insufficient continuous purging of the water being distilled, water contamination with elements that cause foaming, scale buildup on surfaces, excessive distillation frequency, a very high water level, problems with the droplet separator baffles, the distiller operating at pressures different from its design specifications, etc.



Some chemical products can be used to prevent scale buildup in the distiller, but the best solution is to soften the water by ion exchange (sodium-cycle resin softener), ensuring continuous purging of the distiller, due to the excess alkalinity, which can form foams that cause carryover.

From the previous figure, a still using "mechanical thermo-compression," let's look at the basic operation:

The vapor produced in the heat exchanger-evaporator, which is heated by thermo-compression (or initially by electric resistance heaters), is discharged into a separation chamber. In this chamber, water droplets are removed through labyrinths and filters, and the vapor is drawn in by the compressor's suction at approximately 93-95°C (-1.2 to -1.3 m.w.c.). It is then compressed by the compressor, increasing its pressure (0 m.w.c.) and therefore its temperature (+100°C).

Mechanical work from the electric motor is added, which is transformed into temperature and pressure. The discharge of these hotter vapors collides with the tubes of the heat exchanger-evaporator containing the saline water to be evaporated. The vapor from the compressor condenses, and the saline water evaporates.

The heat of vaporization is almost exactly the same as the heat of condensation, approximately 600 kcal/kg. The temperature difference allows heat transfer from the condensate to the saline water, since there is a difference caused by the different pressure and temperature conditions on each side of the process.

This phenomenon allows distillation to occur in a nearly closed cycle using very little energy, only compensating for losses (with electrical resistance).

The condensed water releases its non-condensable gases into the atmosphere (CO_2, O_2, N_2, NH_3, etc.), and the water continues by gravity to the heat exchanger with cold feed water before exiting.

1200 liters SOFTENER C.W.T. design